VVER-1200/491 Design & The Scope of SMRs

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INTRODUCTION

Presentation Scope

- I will speak briefly on two subjects
- The first is the VVER-1200/491 Generation III+ reactor design
- The second is the scope of designs for small modular reactors, SMRs
- Essentially all of the graphics related to the VVER-1200/491 design are extracted from a 2013 presentation by former STUK director Jukka Laaksonen, now with Rusatom Overseas, which contains no copyright restrictions.

PLEASE ASK QUESTIONS!

- If you have a question, please stop me and ASK.
- If I cannot answer your question right away, give me your business card (or your name and email address) at the end of the session, along with your question, and I will get you an answer next week.
- If a question occurs to you after this session, don't hesitate to get in touch. I can be reached at: steven.sholly@boku.ac.at

VVER-1200/491

VVER-1200/491 Projects

- **The VVER-1200/491 standard nuclear power plant design is one of two Generation III+ designs currently being offered by Rosatom (Russian Federation).**
- **There are VVER-1200/491 projects under construction (Astravyets, Belarus; Baltic, Russian Federation; Hanhikivi, Finland; and Leningrad II, Russian Federation; Hanhikivi, Finland) or in planning (Akkuyu, Turkey; and Paks, Hungary) in a number of countries.**
- **The other design in this class is the VVER-1200/392M, which is being built at the Novovoronezh II nuclear power plant and is planned for additional projects (Tsentral & South Urals, Russian Federation; I will not further address this design other than to note its existence.**

What is the VVER-1200/491?

- The VVER-1200/491 is based on a four-loop, light water cooled & moderated pressurized water reactor (PWR) with horizontal steam generators
- The design lifetime for the VVER-1200/491 is 60 years, and the lifetime availability target is 92%
- The reactor is housed in a double, large dry containment that rests on a 2.4 meter thick common reinforced concrete foundation
- The primary (inner) containment is a 1.2 meter thick, steel-lined, pre-stressed concrete structure with a 1 meter thick dome; free volume is 75,000 cubic meters
- The secondary (outer) containment is a reinforced concrete structure with a wall thickness of 0.8 meters

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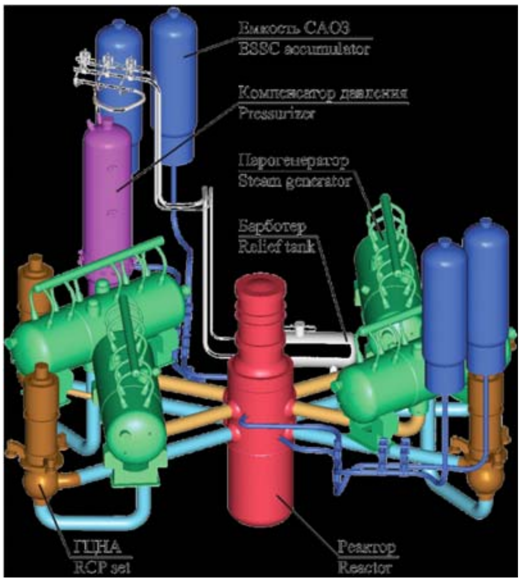
VVER-1200/491 Reactor Coolant System Layout



Design Features - 1

- Thermal power, including pump heat, of 3220 MW
- Nominal gross electrical capacity of 1170 MW; nominal net electrical capacity of 1082 MW (house loads of 88 MW)
- Fuel cycle durations of 12-24 months are possible
- Main coolant pumps are single-stage, water-cooled & lubricated
- Two turbine options are available (full-speed 3000 rpm and half-speed 1500 rpm)
- Four trains of active safety equipment
- One or two trains of passive safety equipment for steam generator and containment heat removal

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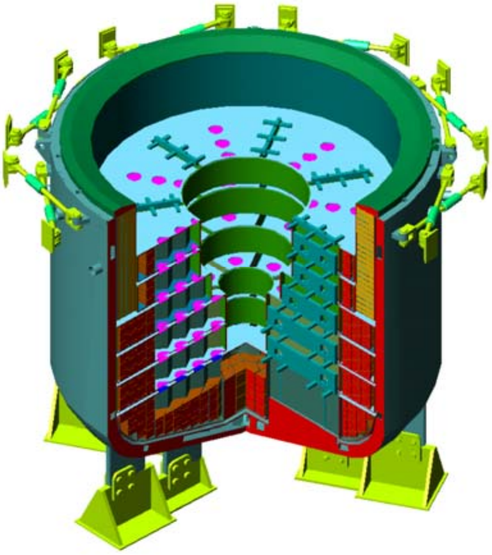
Design Features - 2

- Core catcher and passive autocatalytic recombiners (PARs) provided
- Reactor core comprised of low-enriched uranium (5% maximum) or mixed oxide (MOX) zirconium alloy clad fuel
- Emergency feedwater, high pressure injection, low pressure injection, and residual heat removal systems are 4×100% capacity
- Emergency boron injection and containment spray systems are 4×50% capacity
- There are two (2) 100% capacity refueling water storage tanks inside the primary containment
- There are four (4) 100% capacity emergency diesel generators and two (2) 100% capacity beyond design basis accident (BDBA) diesel generators

VVER-1200/491 Core Catcher



Passive Autocatalytic Recombiners (PARs)

Design Features - 3

- Steam generator passive heat removal system (PHRS-SG) and containment passive heat removal system (C-PHRS) are 4×33% capacity
- There are four emergency heat removal tanks (EHRTs); operation of 3 out of 4 provides cooling for 24 hours; operation of all 4 provides cooling for 72 hours; the tanks can be cross-connected
- Four trains of PHRS in the EHRTs, 18 heat exchangers per train, total 450 cubic meters of water in the EHRTs
- An installed battery-driven pump can fill the EHRTs or the spent fuel pool from separate storage tanks
- Connections are available for two transportable diesel-driven pumps to refill the EHRTs and spent fuel pool

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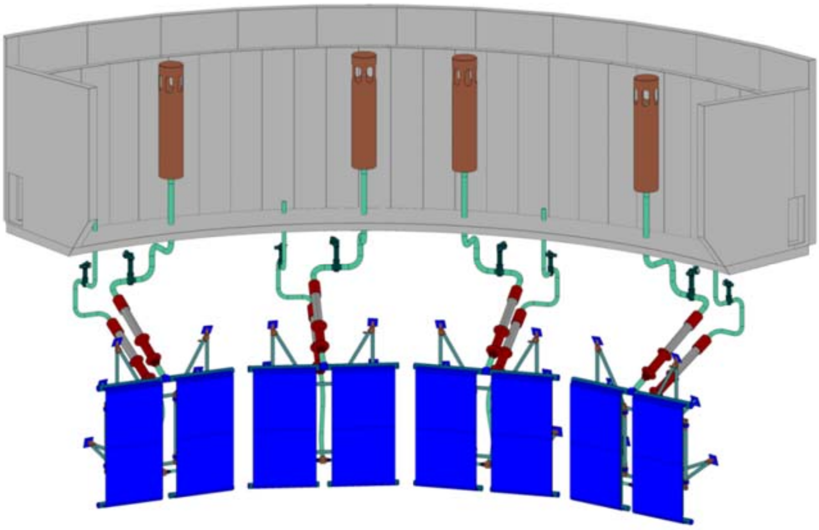
VVER-1200/491 Passive Heat Removal System



Design Features - 4

- Safe shutdown earthquake is 0.25g peak ground acceleration (PGA), can be upgraded to 0.41g without changes to plant layout; mean plant level fragility is 0.51g PGA.
- Tornado protection is Enhanced Fujita Scale F3 (F4 optional)
- Aircraft crash protection is 5.7 tonne aircraft
- Design extension conditions (DECs) include:
  - Failure of all sources of AC power for 8 and 24 hours
  - Loss of spent fuel pool cooling for 8 and 24 hours
  - Complete loss of feedwater
  - Anticipated transients without scram (ATWS)
  - Crash of heavy (400 tonne) aircraft

Preliminary PSA Results

- Preliminary probabilistic safety assessment (PSA) results are available for internal events only
- Mean core damage frequency at power estimated at 1.4×10^{-7}/a
- Mean core damage frequency at shutdown estimated at 4.6×10^{-7}/a
- Total core damage frequency estimated at 7×10^{-7}/a
- Mean limiting accident release frequency (Russian legal definition, OPB-88) estimated at 1.8×10^{-7}/a
- Mean large release frequency due to containment bypass or failure of containment isolation estimated at 3.7×10^{-9}/a
- As with all PSA results, uncertainties and scope limitations exist; the numbers are indicative only

VVER-1200/491 Cost Estimate

- The estimated capital cost for Hanhikivi Unit 1 in Finland is €6 billion (according to the World Nuclear Association, WNA)
- This may be an overnight estimate for the nuclear and turbine buildings
- Whether the estimate includes other costs is unclear (e.g., owners costs, power conversion system, grid connection, circulating water & service water systems, security, water, wastewater, insurance, taxes, financing, etc.)
- The €6 billion estimate is an underestimate if it is an overnight cost estimate; the likely cost range is probably in the range of €8-12 billion if it is completed on schedule, and higher if not

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Further Information on the VVER-1200/491 Design

- IAEA Advanced Reactor Information System, https://aris.iaea.org/PDF/VVER-1200(V-491).pdf
- Fennovoima, Application for a Construction License pursuant to Section 18 of the Nuclear Energy Agc (990-1987) for the Hanhikivi Nuclear Power Plant, updated August 5, 2015 (available only in an online format - not downloadable), https://issuu.com/fennovoima/docs/construction_license_application_pu
- Fennovoima, FH1 Program PSAR Chapter 1 General Plant Description, June 1, 2015 (available only in an online format - not downloadable), https://issuu.com/fennovoima/docs/psar_chapter_1
- VVER-1200 (AES-2006 wall chart, http://www.rusatom-overseas.com/upload/aes_2006_wallchart.pdf

SMALL MODULAR REACTORS (SMRs)

What is a Small Modular Reactor?

- **A small modular reactor (SMR) is a reactor producing up to 300 Mwe (but usually smaller), built in factories, and transported as modules to installation sites**
- **There are three SMRs under construction in Argentina, the People's Republic of China, and the Russian Federation)**
- **Current SMR Design Concepts: Argentina** (CAREM-25, CAREM-100)**, Canada** (IMSR)**, France** (FlexBlue)**, India** (AHWR300)**, Japan** (4S, DMS, GTHTR300, IMR)**, People's Republic of China** (ACP-100, HTR-PM)**, Russian Federation** (BREST300-OD, ELENA, KLT-40S, RITM-200, SVBR-100, VK300, VVER-300)**, South Africa** (HTMR100, PBMR-400)**, South Korea** (SMART)**, United Kingdom** (U-Battery)**, United States** (4GM, EM2, ENHS, Flibe Energy, IRIS, mPower, NMR, NuScale, PRISM, RS-MHR, SMR160, SSTAR, TWR, Westinghouse SMR)

Asserted SMR Advantages

- Modular construction of nuclear units in smaller increments than Generation III and III+ (25-300 MWe vs. 1200-1600 MWe), better suited to remote sites, small grids, and possibly grids with modest demand growth
- Enhanced safety margin through inherent passive safety features (this remains to be seen in practice)
- Better affordability (this is certainly debatable)
- More limited financial risk per unit time and more limited absolute financial risk than Generation III and III+
- Potential for innovative systems such as cogeneration, non-electric applications, and hybrid nuclear/renewable system (this is speculative)

Perspective - 1

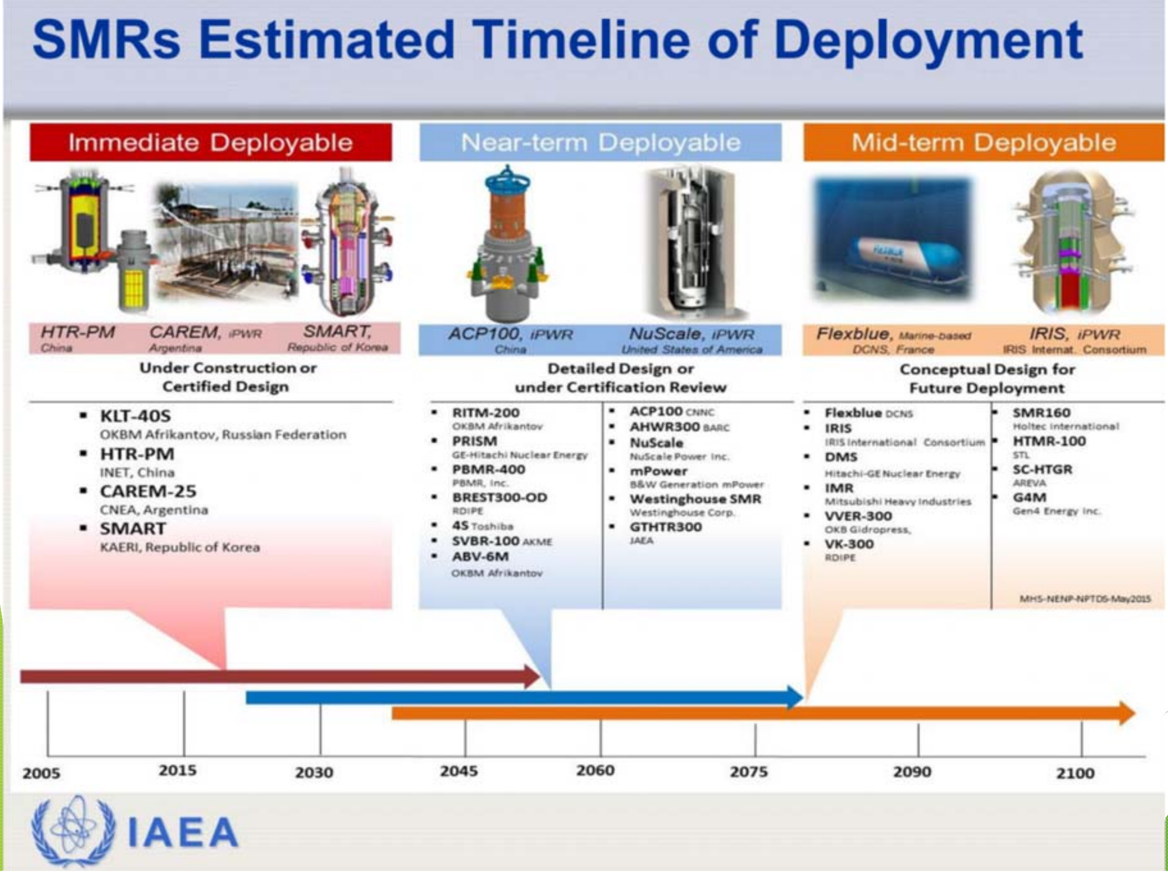
- Some of the SMR designs are intended for military applications of nuclear power, and are unlikely to attract much if any commercial attention
- There are too many designs (more than 50) competing for a very limited niche market
- Economics and the market will prevail – only a small number of SMR designs will survive the conceptual design stage, and most will never be built
- SMRs will likely only be built in developed countries if licensing requirements are reduced (and this seems unlikely in most markets following the Fukushima Daiichi accidents in 2011)
- There is essentially no market for SMRs in large, well developed grids serving large populations (unless a government builds them)

Perspective - 2

- Only five SMR designs are licensed (SMART, KLT-40S, CAREM-25, HTR-PM, and PWHR-220), three are under construction (SMART not yet), and only one is in operation (old PHWR-220 units)
- Poor history to date for both liquid metal cooled reactors (LMRs) and more exotic designs such as molten salt reactors (MSRs), and poor history to date for gas-cooled reactors (except U.K. Magnox and AGRs, and no more of these are planned)
- Deployment schedules for Generation IV reactors are slipping badly (predictably – this is what I said 14 years ago would happen, and I have been proven correct) compared with ten years ago because of problems with materials, fuel, funding, lack of relevant experience, and lack of utility interest – some of these designs were supposed to start commercial deployment in 2015 (none did) and be commercially viable (except for MSR) by 2025 (likely none will without extensive government funding)

IAEA Forecast for 2040 SMR Demand

- The IAEA has forecast a demand for 500-1,000 SMR units by 2040.
- As is all too often the case for IAEA forecasts, this forecast is hopelessly optimistic.
- Just for example, the total current worldwide nuclear capacity is 392 GWe. IAEA’s "high" forecast for 2030 (less than 14 years from now) is 632 GWe. This would require the construction of 240 GWe of new nuclear capacity within the next 14 years. Even if this were to be met entirely by 1600 MWe units, this would require 150 such units. There are currently 60 nuclear units under construction with an aggregate capacity of 59 GWe. There is simply no way that this capacity plus another 181 GWe of capacity will be completed by 2030.
- Similar projections are made by OECD/NEA and the World Nuclear Association – these will also not be met.



SMRs Estimated Timeline of Deployment

Immediate Deployable

Under Construction or Certified Design

- **KLT-40S**
  OKBM Afrikantov, Russian Federation
- **HTR-PM**
  INET, China
- **CAREM-25**
  CNEA, Argentina
- **SMART**
  KAERI, Republic of Korea

Near-term Deployable

Detailed Design or under Certification Review

- **RITM-200**
  OKBM Afrikantov
- **PRISM**
  GE-Hitachi Nuclear Energy
- **PBMR-400**
  PBMR, Inc.
- **BREST300-OD**
  RDIPE
- **4S** Toshiba
- **SVBR-100** AKME
- **ABV-6M**
  OKBM Afrikantov
- **ACP100** CNNC
- **AHWR300** BARC
- **NuScale**
  NuScale Power Inc.
- **mPower**
  B&W Generation mPower
- **Westinghouse SMR**
  Westinghouse Corp.
- **GTHTR300**
  JAEA

Mid-term Deployable

Conceptual Design for Future Deployment

- **Flexblue** DCNS
- **IRIS**
  IRIS International Consortium
- **DMS**
  Hitachi-GE Nuclear Energy
- **IMR**
  Mitsubishi Heavy Industries
- **VVER-300**
  OKB Gidropress,
- **VK-300**
  RDIPE
- **SMR160**
  Holtec International
- **HTMR-100**
  STL
- **SC-HTGR**
  AREVA
- **G4M**
  Gen4 Energy Inc.

MHS-NENP-NPTDS-May2015

Further Information

- Hadid Subki, Technology Development Status Report: Small Modular Reactors, International Atomic Energy Agency (IAEA), 10th GIF-IAEA Interface Meeting, Vienna, Austria, 11-12 April 2016, https://www.iaea.org/NuclearPower/Downloadable/Meetings/2016/2016-04-11-04-12-INPRO/021_Small_Modular_Reactor.pdf

Thank you for your attention!